An Advanced CuCu Hybrid Bonding For Novel Stacked CMOS Image Sensor

Y. Kagawa[1], N. Fujii[2], K. Aoyagi[2], Y. Kobayashi[1], S. Nishi[1], S. Takeshita[1], J. Taura[1], H. Takahashi[2], Y. Nishimura[2], K. Tatani[2], M. Kawamura[1], H. Nakayama[1], T. Nagano[2], K. Ohno[2], H. Iwamoto[2], S. Kadomura[1], T. Hirayama[2]

[1]Sony Semiconductor Manufacturing, Japan, email: Yoshihisa.Kagawa@jp.sony.com
[2]Sony Semiconductor Solutions, Japan

Abstract—We have successfully introduced the advanced CuCu hybrid bonding to the novel stacked back-illuminated CMOS image sensors (BI-CIS). To form the rigid Cu-Cu connections, we optimized the surface flatness of Cu connection pads that ensured both electrical connectivity and fabrication process margin. In this study, the tolerance of Cu sticking-out from the viewpoint of bonding process was quantitatively calculated. The electrical test results showed that our robust CuCu hybrid bonding achieved fine-pitch and large-scale connections.

I. INTRODUCTION

We announced a stacked BI-CIS with CuCu hybrid bonding that joins a CIS and an image signal processor (ISP) [1]. Hybrid bonding is a method that connects two substrates by Cu-Cu metal bonding and by inter layer dielectric (ILD)-ILD oxide bonding at the same time [2]. The Cu connection pad is located on top of the BEOL layer, and it never interferes with the MOS-FET during the fabrication process. As shown in Figure1, it enables enormous circuit design flexibility and further chip size reduction can easily be achieved [3].

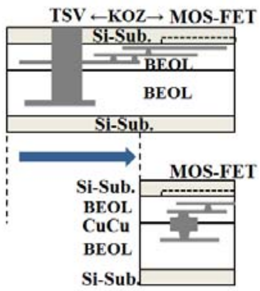

Fig. 1. Schematic diagrams of bonded substrates with TSV (upper) and with hybrid bonding (lower)

To make a robust Cu-Cu connection, to control the surface flatness of Cu connection pad is an important factor. When the conventional BEOL CMP process is used, the surface of the Cu tends to recess to some extent depending on the Cu wiring width. The concern is that the electrical connectivity of the recessed Cu pads may be adversely affected when they are bonded. On the other hand, when our controlled CMP process, which intentionally fabricates very flat or slightly sticking-out Cu pads, is used, better Cu-Cu electrical connection is expected as shown in Figure2. In this study, the tolerance of Cu sticking-out from the viewpoint of bonding process was quantitatively calculated.

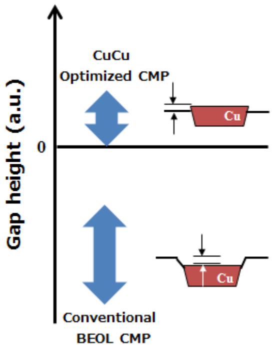

Fig. 2. Schematic diagrams of surface flatness of conventional CMP and CuCu optimized CMP

II. EXPERIMENTAL

As shown in Figure3, we estimated the sticking-out margin of Cu connection pad by applying the theoretical formula of conventional oxide bonding [4] to the CuCu hybrid bonding.

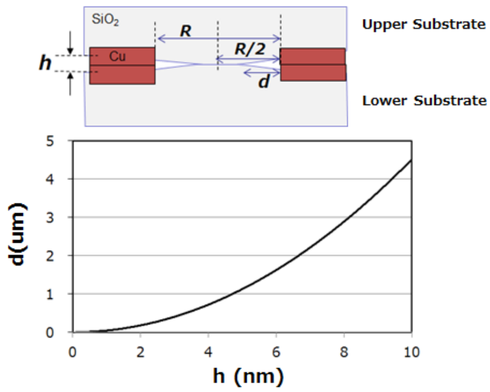

Fig. 3. Theoretically estimated sticking-out margin of Cu connection pad

From this estimation, the relationship between the stick-out height and the non-bonded distance can be evaluated. It can be considered that the space between two adjacent Cu connection pads should be wider enough than the non-bonded distance to bond two substrates firmly. The scanning acoustic microscopy (SAM) image in Figure 4 shows that the 300 mm wafers polished by our controlled CMP process could be firmly bonded without any bonding voids.

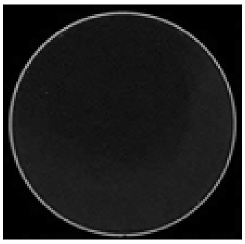

Fig. 4. Bonding result of two wafers polished by CuCu optimized CMP

III. RESULTS AND DISCUSSION

The electrical properties of our CuCu hybrid bonding were investigated by using a test module which was fabricated on 300 mm wafer. The test module contains a number of Cu-Cu connections whose fabrication process is identical to that of our new BI-CIS.

Figure5 shows the resistance distributions of Cu-Cu connections. The pitch of the adjacent Cu-Cu connection is 4 um, and the number of connections is 3M. As shown in Figure5, the tight distributions show good connectivity.

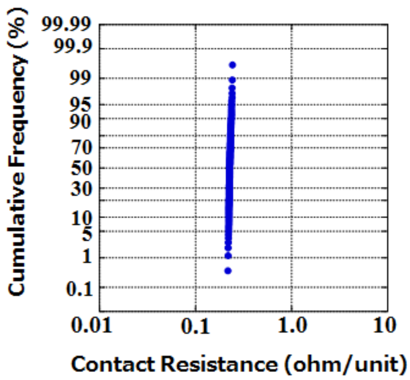

Fig. 5. Cumulative plot of contact resistance of Cu-Cu connections

Figure6 shows the leakage current between different potential Cu-Cu connections. The space between different potential Cu-Cu connections is 2 um, and 1k connections are located in the module. It is shown that the leakage current is well suppressed. Extremely low leak current indicates that each Cu-Cu connection is well isolated by the surrounding dielectric.

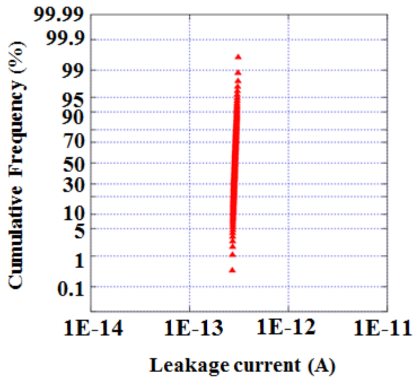

Fig. 6. Cumulative plot of leakage current between different potential Cu-Cu connections

We fabricated a stacked BI-CIS with a 22.5 megapixel 1/2.6 size CIS featuring a 1.0μm unit pixel size and an ISP by using our CuCu hybrid bonding process.

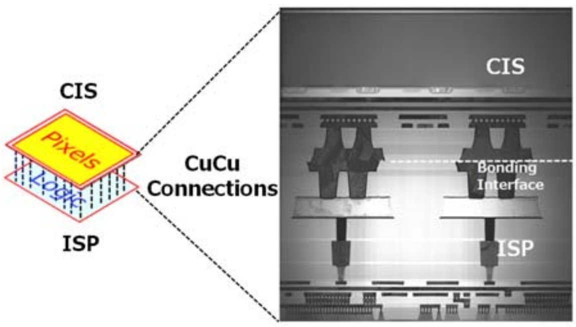

Fig. 7. Cross-sectional view of new stacked BI-CIS with CuCu hybrid bonding

As shown in Figure 7 the upper and lower side Cu pads were firmly connected without any defects at the bonding interface.

IV. Conclusions

In this study, we theoretically estimated the tolerance of Cu sticking-out from the view point of bonding process margin. This quantitative data can be utilized to the design of Cu connection pads. The electrical test results showed that our robust CuCu hybrid bonding achieved fine-pitch and large-scale connections.

References

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